The following is a synopsis of the proposed focused program in Intelligent and Distributed Engineering Design that was co-authored by Mary Mitchell (of the Advanced Technology Program Office) and Simon Szykman of the NIST Manufacturing Systems Integration Division, based on input obtained from the NIST workshops, white papers and other sources. This synopsis was provided, before the formal program presentations, to the panel of NIST and non-NIST experts who were assembled to evaluate a number of proposed focused programs.

INTELLIGENT AND DISTRIBUTED ENGINEERING DESIGN

PROGRAM SYNOPSIS

Executive Summary

This focused program will develop and improve enabling and infrastructural technologies for realizing the design of physical engineered systems (e.g. mechanical, electromechanical, aerospace, electronic, structural, and architectural). The ultimate technical benefits of this program include an improved infrastructure for using and exchanging design knowledge, and for integration of information across time, space and engineering domains. These benefits will translate to broad-based economic benefits through accelerated product development, reduced direct design costs, and improved product quality. The need and structure for such a focused program were discussed with industry at a pair of open workshops. Participants strongly recommended a concentration on frameworks that address key technological issues associated with intelligent and distributed design.

ATP is needed to support the next level of efforts required to move a wealth of foundation research from DARPA, NSF, NASA and related programs into development led by industry. ATP funding can reduce the risk from the type of collaborative research that will be required to achieve these objectives, thereby increasing the competitiveness of U.S. industry and ensuring continued U.S. leadership in this market.

Opportunity

There is a limited window of opportunity to capitalize on the early research from programs like the DARPA Rapid Design Exploration and Optimization (RaDEO), and others funded by NSF and NASA. These efforts are just now yielding a wide range of results that are being widely publicized and published but which require further research prior to commercialization. The collaborative climates in Europe and Asia are ready to utilize this research if the U.S. design tool vendors do not do so first. Typically, design tool vendors are technically sophisticated but small, and must therefore focus their resources on incremental extensions to product lines in focused markets. Large OEMs exert strong pressure to focus work on their firm's internal needs and industry sector. ATP support can motivate collaborative development across design tools and across industries, promoting the creation of cross-industry modular design tools and integration frameworks for complex engineering systems. The ATP is uniquely positioned to reduce the risk of collaboration. ATP funding can leverage the existing U.S. strength in software to ensure continued U.S. leadership in this market.

Background

The design of complex engineering systems is increasingly a collaborative task among designers or design teams that are physically, geographically and temporally distributed. The complexity of modern products means that a single designer can no longer manage the effort. A firm that relies only on its own resources may not be able to react to a market opportunity, can only develop a more limited line of products, and has higher development costs and more quality problems.

Driven by such issues, companies are increasingly staffing only their core competencies in-house and depending on other firms to provide the complementary design knowledge needed for a complete product. Designers are no longer merely exchanging geometric data, but more general knowledge about design and design process, including specifications, design rules, constraints, rationale, and more. As design becomes increasingly knowledge-intensive and collaborative, the need for intelligent computational design tools to support the representation, use, and integration of knowledge among distributed designers becomes more critical.

To assess these and other issues, industry and ATP held open workshops on *Tools and Technologies for Distributed and Collaborative Design* in August, 1997, and on *Intelligent and Distributed CAD*, July, 1998, at NIST in Gaithersburg, Maryland. Dozens of researchers from large and small businesses, government, and academia attended, representing the country's leading engineering organizations and engineering software vendors. The first workshop reached a number of major conclusions. The second workshop resulted in further industry input, and validated the program scope and the initial workshop conclusions. More generic application frameworks for linking new and existing engineering applications to one another, and to the communications infrastructure, will have farther reaching impact and will be applicable across a broader spectrum of industries than point solutions. Without ATP involvement, industry will not develop the frameworks that are broadly applicable to intelligent and distributed engineering problems. Rather, companies will continue to develop point solutions that will result in the emergence of numerous incompatible approaches and data formats, which will in turn inhibit interoperability and the evolution toward successful integration among distributed people and software tools. ATP should form an Intelligent and Distributed Engineering Design focused program and center it around frameworks and technologies for design knowledge capture and reuse which facilitates collaboration across space and time discontinuities.

Potential for U.S. Economic Benefit

Significant reductions in time and cost of designing complex engineered systems can be achieved. Although the actual cost of design is typically 5% of the cost in production systems, decisions made during the design stage determine 70% of the product's cost over its life. When a jet engine costs $2 billion to develop (as the General Electric GE 90 for the Boeing 777 did) or a new model automobile costs $3-6 billion (Ford), the potential impact of this program is substantial. This will translate to benefits for consumers through lower costs, improved quality and faster introduction of new technology into the marketplace. They will benefit U.S. industry through increased profit due to lower costs, and through improving market share and sales volume of U.S. products domestically and abroad. It is also expected that the kinds of collaboration infrastructures that will be developed will themselves result in new markets. In other words, not only will existing industry benefit, but it is likely that a new industry which provides frameworks for intelligent and distributed design in industry will emerge. The following goals are targeted as realizable objectives:

- **Increased competitiveness of U.S. industry by reducing design and production costs as well as product development time.** Specific targets include: reduction in direct design costs of 10% - 30%, reduction of time-to-market of 25% - 75%, and reduction of defect rates and engineering change requests of 23% - 70%. The range in values reflects the variances from one industry to another on the realistic degree of improvement.
- **Established application frameworks for supporting intelligent and distributed design.** The risk of product development within a defined framework will be greatly reduced, and the ability to market products will be greatly increased, leading to more and better software products for intelligent and distributed design. ATP participation will foster collaboration, leading to unified technology development between companies.
- **Increased support of collaboration among distributed designers, design teams, and companies.** The benefits should permit designers to delay detailed design longer and permit members of a distributed design teams to take control of portions of the design and allow review by remote colleagues. This will allow team members to be used most effectively.
- **Increased capture and linkage of design information across various stages of the product life cycle.** Benefits will include improved reuse of design information across product families, and more rapid redesign efforts. In addition to reducing development time, improved feedback of knowledge into subsequent design processes will increase quality and reduce warranty and repair costs later on.

Good Technical Ideas

The enabling and infrastructural technologies identified by industry as significant were:

Distributed Collaboration Tools. Frameworks are needed to foster effective collaboration across disciplines, space, and corporate boundaries. Mechanisms will be required for the establishment and search of profiles of the capabilities of potential partners with the best available technologies for responding to a market opportunity. The development of tools for modeling design and analysis strategies, negotiating a common strategy across a team, and managing the execution of the strategy as the project proceeds will also be required. Techniques for wrapping existing systems to interface with the frameworks will be needed, as well as mechanisms for allowing partner access to information without compromising proprietary data.

Design Constraint Tools. Design is distributed not only over space, but also through time (among different stages of product development), resulting in series of models which become unsynchronized and incompatible. Each stage has distinctive knowledge requirements and produces results which offer opportunities for knowledge sharing. To improve this situation, tools will be required for set-based design that enable designers to compare sets of alternatives or ranges of parameterized options concurrently before choosing which solutions to pursue further. This will also require the development of expanded formalisms for representing the dependencies among design variables and software tools to capture and manipulate these dependencies.

Design Reuse Library Tools. Design reuse can be facilitated by libraries of self-configuring components. This will require the development of knowledge templates to characterize existing designs and serve as the framework for acquiring new design knowledge efficiently. The development of techniques to translate this knowledge so that it can be reused in component libraries will also be required. A new generation of tools will be needed to capture information such as design intent and rationale, to enhance the reusability of previous designs.

Formal Representations and Design Knowledge Tools. Advances in the development of formal (including mathematical) representations are needed to capture the intent and logic behind a design (including functions to satisfy design constrains and the trade-offs that justifying it), the processes that can produce it, and the critical parameters needed to estimate cost. Such representations require the extension of engineering taxonomies, the development of constraint-based and functional calculi and the tools to manipulate constraints. These representations must be modular and permit the extraction of parts of a complete model and the ability to collect and integrate previously unrelated component models into a whole. A new generation of tools based on these representations will be needed to capture, manipulate, and exploit the design knowledge.

Metrics and Supporting Tools. The development of metrics and supporting tools will occur in three areas: the internal characteristics of a given design effort, the interaction between design and other phases of the product life cycle, and the overall distributed process. Mechanisms will be developed to allow designers to reason about the impact of alternative decisions on a subsequent phase of the life cycle. Methods will be developed to capture information about the consequences of design decisions on later development phases, and feed this information back to designer. These approaches will extend current industry metrics for producibility, maintainability, reusability, and others. Software tools will be created to link metrics with distributed design activities.

Strong Commitment by Industry

There is a strong recognition by industry of the need for work in the area of intelligent and distributed engineering design. ATP received numerous industry white papers on the infrastructure required to support advances in this area. Over a half-dozen ATP awards made through recent general competitions had strong overlap with the agenda of this proposed program. These proposals along with the industry participation and level of enthusiasm at the NIST workshops show a high level of industry interest in, and commitment to, an ATP Intelligent and Distributed Engineering Design focused program. Industry and academia have undertaken some foundation research in relevant areas through efforts funded by DARPA, NSF, NASA and private sector sources.

Opportunity for ATP Funding to Make a Difference Now

Despite the level of research in industry, academia, and government, and the number of ATP awards supporting various projects relevant to this area, there is a wide gap between the needs of engineering organizations that develop complex engineering systems and the planned capabilities of software products which support these industries. The gap is widening with the increased reliance on outsourcing and the difficulties this adds to managing product development processes. The Intelligent and Distributed Engineering Design ATP program is concerned with developing key enabling and infrastructural technologies to help ensure the continued U.S. leadership in software and engineering systems markets.

Neither design tool vendors nor large OEMs will invest in technologies aimed at benefiting the entire industry sector. In the past, large OEMs have tended to standardize on specific sector-oriented design tools and dictate their use by suppliers, placing a considerable burden on small and medium-sized suppliers. Large OEMs have begun to recognize that this strategy may not be in their long term interest. Because NIST does not favor any single industry or design technology, ATP support can motivate collaborative development both within an industry and across multiple industries, promoting a vision for modular, plug-and-play design tools that are useful to many industries.

The development of generic application frameworks for distributed design is inherently risky and is beyond the reach of most individual firms. Risks and initial development costs are sufficiently high to require some level of cost sharing. While standards development *per se* is outside of the ATP mission, effective execution will require close interaction with standards efforts, both to draw on the baseline of existing standards technology, and to focus standards bodies on areas in which further work is needed.

With ATP support, there is a great opportunity for joint ventures that can share in development costs and provide convincing demonstrations of the advantages of intelligent and distributed engineering design. In this way, an ATP role will also foster collaboration among companies that would otherwise pursue development entirely on their own. One of the most significant benefits of ATP participation is the improved ability for interoperability, between companies as well as individual software tools, that could result from unified development efforts and the emergence of standardized approaches. This would avoid a reoccurrence of the main barrier to interoperability among traditional CAD tools, specifically, the fragmenting of the market with a large number of system-specific or proprietary formats resulting from many uncoordinated technology development efforts.

There is a limited window of opportunity to reap the results of foundation research in this area and ready these technologies for commercialization. Industry/government partnerships such as this ATP Focused Program are particularly important to encourage the development of new technologies that involve very high risk.

Scope

Activities that may be supported by ATP include the development of:

- formal methods and architectures for the definition of distributed design frameworks,
- technologies for representing, managing, manipulating, and exchanging design knowledge across space and time; interfacing to existing systems; authorizing appropriate access to shared information; and defining formalisms for effective storage, search, and retrieval of design knowledge,
- critical demonstrations of technologies and their implementations as effective components in distributed design frameworks,
- industry consortia and other fora for cooperative requirements analysis, research, development, demonstration, and capture of metrics.

Activities that will not be supported by ATP include the development of:

- point solutions which operate as all-in-one packages aimed at a specific industry or vertical market,
- information infrastructure components that are rapidly advancing independently of this program (e.g., middleware, traditional geometry-based CAD systems, advanced network (Internet/intranet) infrastructure, conferencing tools, electronic commerce technology development, etc.) Note that these components may be integral facets of a project, but are not within scope of this proposed focused program. The focus of a proposal should be on developing infrastructure for intelligent and distributed engineering design, and not on infrastructure for information technologies.

Project proposals must clearly establish that the **technical goals are critical to intelligent and distributed engineering design** and are unlikely to be accomplished in a timely manner without ATP support.